

posite envelope can be formed by the combination of the low passed versions of the signals except for the signal that is being envelope modulated. That is to say, the composite envelope of effects 1 and 2 modulate the high passed signal resulting from effect 3. In order to calculate the output force, the high passed signal is multiplied by its modulation envelope and each of the signals that are likewise modulated are summed.

[0136] One advantage to combining two or more commanded effect waveforms with the present invention, instead of simply adding the waveforms together, includes providing a more centered range of motion for the oscillating inertial mass of the actuator. As explained above, adding the waveforms may cause the inertial mass to oscillate about a point close to an end of travel, which dampens and/or clips the output forces. The present invention centers the inertial mass closer to the center of its range of travel. In some embodiments, a resonant filter can be used to combine multiple commanded effects, which centers the inertial mass still further, as explained above.

[0137] FIG. 16 is a block diagram 380 illustrating the filters of the present invention, which can be used for combining multiple effects. This block diagram includes the operations of equation (15) set forth above. Each effect 382 is shown on the left, defined by magnitude (M), frequency (w), and phase (p). A frequency domain filter 384 is applied to each effect, each filter including high pass (Bh) and low pass (Bl) filters. The high passed component and the low pass component are passed through corresponding high and low pass components of the normalization function 386. The waveforms and envelopes are synthesized in block 388 from the input parameters M, w, and p and the outputs from normalization function 386, and the outputs from the various synthesis blocks are added, multiplied, and combined, as shown, in accordance with equations (14) and (15) in the time domain filter 390. An overall gain is provided by the operations 392. Saturation is provided by a gain block 394, in those embodiments desiring such an operation, and a saturation block 396 which saturates the amplitude of the waveform to the predetermined limits of the hardware outputting the forces. The saturated waveform is sent to actuators and related circuitry (not shown) to output the force to the user of the interface device.

[0138] While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, permutations and equivalents thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. For example, many different types of haptic sensations can be provided with the actuator assembly of the present invention. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention. It is therefore intended that the following appended claims include alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

What is claimed is:

1. A method for providing a tactile sensation using an inertial actuator in an interface device, the method comprising:

receiving a commanded low frequency at which to output said tactile sensation to a user of said interface device; and

providing a plurality of bursts of a higher frequency signal, said bursts being provided approximately at said low frequency to control said inertial actuator to output said tactile sensation, wherein said tactile sensation conveys said commanded low frequency to said user.

2. A method as recited in claim 1 wherein said inertial actuator includes an inertial mass that is oscillated bi-directionally, and wherein said bursts each control at least three changes of direction of said inertial mass at said higher frequency.

3. A method as recited in claim 1 wherein said higher frequency is high enough so as to cause said user to feel each of said bursts as a single pulse.

4. A method for providing haptic sensations using an inertial actuator in an interface device, the method comprising:

receiving a commanded low frequency at which to output a tactile sensation to a user of said interface device;

determining a higher frequency; and

combining said low frequency with said higher frequency to provide a resulting signal used to output a tactile sensation at said higher frequency, said tactile sensation conveying said commanded low frequency to said user.

5. A method as recited in claim 4 wherein said combining includes outputting bursts having said higher frequency at a rate corresponding to said commanded low frequency.

6. A method as recited in claim 5 wherein said burst includes at least three changes of direction of an inertial mass of said inertial actuator.

7. A method as recited in claim 4 wherein said combining includes creating a waveform having said higher frequency, said waveform having an amplitude that varies according to said commanded low frequency.

8. A method as recited in claim 7 wherein said combining includes adding a waveform having said commanded low frequency to a waveform having said determined higher frequency.

9. A method as recited in claim 7 wherein said combining includes using a waveform having said low frequency to modulate the magnitude of a waveform having said higher frequency.

10. A method as recited in claim 9 wherein said combining includes filtering said low frequency waveform and said higher frequency waveform using a low pass filter and a high pass filter.

11. A method as recited in claim 10 wherein said combining includes normalizing said low frequency waveform and said higher frequency waveform.

12. A method as recited in claim 11 wherein said combining includes adding said higher frequency waveform to the normalized, modulated high frequency waveform.

13. A method as recited in claim 7 wherein said higher frequency is approximately at a resonance frequency of a mechanical actuator system of said interface device.

14. A method as recited in claim 4 wherein said inertial actuator in said interface device is coupled to a flexure, wherein said inertial actuator provides an inertial mass that moves bi-directionally to output said low frequency tactile sensations.

15. A method as recited in claim 14 wherein said actuator moves as said inertial mass.